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UNITED STATES GOVERNMENT

memorandum

6303-02M

DATE 05 October 1998

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SUBJECT FOI-097-98

TO: Code 1230, Maria Lloyd

1/6/99

1. In my opinion, the limitations that may have applied in 1986 regarding the distribution of NRL Memorandum Report 5697 dated 8 January 1986, do not apply today. AD - B098 840

2. If you have any questions, please call me at 202-767-2264. It is my recommendation that, as far as NRL jurisdiction (as opposed to NAVAIRSYSCOM's) is concerned, the report should be released.

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To: Commanding Officer, Naval Research Laboratory(Code 1230)

Subj: FREEDOM OF INFORMATION ACT REQUEST (FOI-097-98)

Ref: (a) PHONCON NAVAIR (Code 7.7.6) Ms. Eileen Leshan/NRL (Code 1230) Ms. Maria Lloyd of 21 Dec 98

Encl: (1) C. Martinez ltr of 30 Sep 98
(2) Report entitled, "Projectile Impact Effects on Aircraft Wire Harnesses"

[illegible] discussed in refe[illegible] [illegible] and (2) as a matter under your cognizance for a final determination with regard to release.

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By Direction

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(2)

NRL Memorandum Report 5697

Projectile Impact Effects on Aircraft Wire Harnesses

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January 8, 1986

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Washington, D.C.

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Naval aircraft wiring harnesses, representative of the construction of one carrying the power and signal circuits of an F-14 harness were shot at under controlled conditions to observe the effects produced by the impacts of hostile projectiles. The results of these tests, conducted in the NRL Ballistics Facility, have demonstrated that the effect can be serious and that the combustive reactions from the electrical arcing resulting from the shearing damage of the impact will be more severe for some types of wire insulation than for another. This experiment provided a direct comparison between wiring insulated with an aromatic polyimide insulation system and a radiation crosslinked ethylene tetrafluoroethylene (modified ETFE) insulation. Despite the fact that the same electrical power was applied to both types, the harnesses of the aromatic polyimide wires ignited and burned, whereas the other did not. From the way the fire propagated along the harnesses, tripping more circuit breakers as additional wires were engulfed in flames, it was apparent that the aromatic polyimide forms a carbonaceous char that is conductive. The reaction then causes the short circuiting to progress along the harness as long as there is a voltage potential between adjacent wires.

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CONTENTS

PROJECTILE IMPACT EFFECTS ON AIRCRAFT WIRE HARNESSES

INTRODUCTION

A study was initiated recently at the Naval Research Laboratory to evaluate the effects of hostile projectiles impacting on aircraft wiring harnesses. The results of tests conducted in the NRL Ballistics Impact Facility have demonstrated that the effects can be serious and that combustive reactions from the electrical arcing resulting from the impact will be more severe for some types of wire insulation than for others. The tests demonstrated that wiring with an aromatic polyimide insulation will react more severely than wiring with a radiation crosslinked modified ethylene tetrafluoroethylene insulation. The nature of this reaction and the description of the test will be more completely described in this report.

There has been very little published about such reactions in either laboratory experiments or from in-service experiences, although it should be a primary concern, since combat survivability is a major design goal for our fighter aircraft. In a literature search it was noted that the majority of committee reports and newsletter items on Aircraft Survivability and Battle Damage Repair describe extensively the methods and materials that are being developed to repair damage to fuselage skins--both metal and composite. In full-scale tests, decommissioned airplanes are being shot at with small arms, cannons and missiles to determine the extent of damage to the skins and structures. Other components being studied for vulnerability and repair processes are: engines, fuel tanks, rotor blades, tires and transparencies (1). Based on reactions observed in this study it would be judicious to include wire harnesses, carrying full power, in this list of components.

Electrical engineers at the NAVAIR Engineering Support Office at NARF, Norfolk, being aware of this potential hazard, conducted some experiments. They found that small projectiles (BB's fired from a Crossman air gun) would break wires and produce short circuits between wires of opposite polarity in a harness energized with 110 volt, 60Hz line power. They observed that some wire insulations would burn and others would not when the short circuit arcing occurred. This concern led to the present, more comprehensive study of the reaction conducted at NRL with a more controlled, service simulated system. These experiments were monitored and recorded on a closed-circuit TV so that the events could be viewed from outside the experimental chamber during the firing and the event could be recounted in detail by later showings of the action that occurred in real time. A ten-minute, narrated videotape report has been prepared in order to facilitate later viewing of the action observed in this experiment.

Manuscript approved October 11, 1985.

EXPERIMENTAL PROGRAM

The experimental system was prepared with considerable advice from NESO engineers in order to study the reactions of operational aircraft wiring to impacts from combat projectiles. Thus, the laboratory system was designed as nearly as practical to simulate the service scenario, and the two wire types tested were qualified by the Navy for combat aircraft service.

The overall test set up is illustrated in Figure 1, and a schematic of the electrical system is shown in Figure 2.

1. Description of Wire Harnesses

The two wire types used to construct the harnesses tested in this study were: MIL-W-81381/11 and MIL-W-22759/34. The MIL-W-81381/11 wire type is insulated with an aromatic polyimide film, applied as a wrapped tape. The MIL-W-22759/34 wire type is insulated with an extruded modified ethylene tetrafluoroethylene polymer that is radiation crosslinked. For this test, wire bundles were fabricated from each of these wire types and mounted so as to simulate conditions which are representative of standard Naval aircraft construction.

The first set of harnesses consisted of both single wires of MIL-W-81381/11 and shielded cables, designated as GC-875MR. These harnesses were constructed at NRL from wires and cables removed from an F-14 that was manufactured by Grumman in November 1980. This aircraft is identified as the Bureau Number 161157, Grumman Fabrication Number 384, that became a Strike Aircraft on 24 April 1981. The wires and cables were taken from the area around the cockpit and the lower right foreward fuselage under the cockpit. They all appeared to be in very good condition and were found to be dielectrically sound when tested prior to the projectile impact events.

All of the harnesses used in the experiments were constructed so as to be representative of F-14 harnesses, consisting of approximately 56 single wires in sizes from 16 to 24 and 10 cables of various amounts of 20 and 26 size wires. When laced tightly the harnesses measured approximately 3/4-inch in diameter.

A representative wire harness of approximately 3/4-inch diameter that is typical of an F-14 installation was described to NRL by the NESO personnel so that the harness specimens could be constructed as nearly as possible to the representative proportions (2). The wires and cables in this representative harness and the specimens constructed for the NRL tests are presented in Table I.

Figure 1 shows a harness installed in the target area. The ADEL harness clamps, type DG-10, hold the harness firmly in place against the aluminum plate that has been coated with zinc chromate corrosion-inhibiting paint, which is representative of an aircraft's interior bulkhead surface. This 65-mil thick aluminum plate is mounted 14 inches behind a 25-mil front plate which represents the outer skin of an F-14 aircraft. Both are made of aluminum alloy 2024-T81 sheets that were obtained from the NARF-NORVA repair shop. It is the same material that is used in the construction and repair of the Navy's F-14's. The painted plate is mounted on the heavy aluminum frame that has a cut-out behind the impact area so the projectile will penetrate and pass on through to a trapping pad of woven Kevlar (R).

2. The Electrical System

Before discussing the components in detail, a few comments are in order. Electric arc-induced ignition and continuing combustion of wire insulation are related to a number of funtamentals of electric circuitry factors which are not completely simulated in this laboratory-assembled test system. Therefore, the following factors must be considered:

a) The initial voltage across a guillotine interruption gap of an insulated wire is a function of the generator voltage, system inductance, and initial load current. The operating condition of this system was conservative in that the power conductors were not carrying load currents. So, therefore, the $L^{di}/_{dt}$ of the interruption across the gap, and to ground, was negligible. Thus, the tendency to ignite and burn is less severe than would be expected if these wires were carrying their respective power loads.

b) The recovery voltage induced from the generator is also less severe than that which would have been present if the voltage regulator had been maintaining a higher internal voltage to account for generator voltage drop from load current. These test conditions tend to understate the combustible character of the aromatic polyimide insulation.

c) The time for which the arc-inducing voltage is impressed on the insulation is representative of actual service conditions since these circuit breakers are the type used in Navy aircraft. Therefore, the subtransient reactance-induced voltage in this test setup is similar to that of an on-board test, since the NC-8A generator is routinely used to simulate the on-board generators in ground-check maintence of these aircraft. Further, the 60 KVA power rating of the NC-8A is of sufficient capacity to insure fast tripping of the breakers. This feature minimizes the time during which voltage must maintain the arc current to initiate combustion.

d) The floating of a portion of the wires in the harness simulates a situation in which some conductors are not connected to loads at the time of the projectile impact. This, too, is conservative in comparison to service conditions.

The cumulative effect of the above considerations is to produce a less severe stress environment for the present tests than can be expected in the operational wiring harnesses installed in aircraft that are actually in service.

Figure 2 indicates the schematic arrangements of the electrical system which is shown in Figure 1.

Electric power to the experimental assembly was provided by a Mobile Electric Power Plant, NC-8A. This diesel engine powered generator is the type used to provide auxiliary power during ground maintenance of military aircraft, rated 115/200-volt, 3-phase, 400Hz, 60 KVA, 0.75 power factor. It is shown in location at NRL in Figure 3, with the cable leading into the building where the firing range facility is located.

A terminal strip was fastened to the free ends of the power wires of the NRL harness specimens for ease of connection to the power supply panel. A full view of the assembled harness of MIL-W-81381/11 type wires and cables and the power distribution panel/terminal strip is shown in Figure 1. In the lower front can be seen the wires carrying the three-phase and ground circuit from the external power supply disconnect to a power junction strip. One set of wires from this junction feed into the panel containing twelve ac breakers. This is an Essential No. 2 Circuit Breaker Panel of an F-14 aircraft. The breakers, in series with each of the 115 volt wires of the harness, are the military aircraft qualified type, Klixon (R) series 7274 .1 (3). The identification numbers that were stamped on the wires and cables of the NRL specimen harnesses, the wire sizes, and the ratings of the circuit breakers connected to the powered wires are listed in Table II for the MIL-W-81381/11 type and in Table III for the MIL-W-22759/34 type.

Just beyond the ac breaker panel can be seen the dc converter that is powered from the 3-phase, 115 volt, 400 Hz input. It is a 100-ampere, 28 volts dc, class C unit, MS 3370-1 manufactured by Wagner Electric Corporation. This is the unit that is used in F-14 aircraft. It provides the 28-volt dc power to the dc circuit breaker panel located next to i in the view shown in Figure 1. The harness wires protected by the fourteen breakers in this panel are also identified in Tables II and III.

3. The Projectiles

In this experiment two different types of projectiles were fired at the harness specimens. The first one was a .30-caliber ball, M-2 bullet, weighing 152 grains. The other was a steel, .30-caliber fragment simulator, weighing 44 grains. The powder loadings were weight-adjusted to propel each at approximately 1000 feet per second. The relative size and shape of these projectiles are shown in Figure 4.

4. The Firing Range

An overview of the test firing range is shown in Figure 5. In the foreground is the rifle, with stock removed, mounted rigidly on a heavy metal stand so it is in line with the target area. Remote firing from the control room is achieved by a solenoid actuated trigger mechanism. The target area consists of two metal frames that are mounted on a metal table about 10-feet down range. The first frame with the aluminum plate representing the aircraft skin is seen in this view, and a closeup of the wiring harness mounted on the second plate is shown in Figure 6. The target area from a side view was seen previously in Figure 1.

IMPACT RESULTS

Once the harness installation was completed the power supply was turned on and each wire connection at the terminal strip was checked with a voltmeter to assure that the harness was powered. The video camera was trained on the target area and turned on. The gun was loaded and cocked, and the room was vacated and secured.

1. MIL-W-81381/11 Harness Tests

a) .30-Caliber bullet

The first shot was conducted with the .30-caliber ball, fired at the MIL-W-81381/11 type harness. The projectile severed wires in the lower part of the harness, and deformed the remaining wires of the bundle. The close-up view in Figure 7 shows the deflection produced by the impact, the carbon deposited on the painted surface, and the hole in the plate where the projectile passed through. A short circuit during the penetration caused arcing that tripped one ac breaker.

In aircraft operations it is a standard procedure to reset the tripped circuit breakers in hopes that power can be restored to the affected electrical components - especially if they are essential to the controls. When the tripped breaker was reset, more arcing and burning occured which re-tripped this breaker and caused four more to trip. These were reset one at a time, and each time there was another arc which tripped it again. When the third breaker was reset the arcing became more violent, with flames engulfing the bundle and more breakers tripping. The intensity of the fire can be seen from the views of the burning harness shown in Figures 8.a and 8.b. The fire and arcing continued to travel along the harness beyond the target area as shown in Figure 8.c. and was successively tripping additional breakers. It appeared that the flames would persist and imminently set fire to the power supply panel. Before this could happen the main power switch was opened and the fire slowed down; however, it continued to burn in the harness for another 15 seconds before it died out.

Figure 9 is a view of the power panel and target area after power was disconnected, showing the breakers that tripped during the arcing and flamming. In all there were 9 ac breakers and 12 dc breakers that tripped open as a result of this fire propagation along the harness.

b) .30-Caliber fragment simulator

The second test in this experiment was conducted on another harness of MIL-W-81381/11 type wire, of the same construction as the first one tested. In this one a .30-caliber fragment simulator projectile was fired. The projectile impacted near the midline of the harness and broke many wires. Arcing and flames began immediately and traveled along the harness for about 10 seconds after the impact. Thesequence of arcing and flaming around the damaged section is clearly visible in the three successive photos of Figures 10.a, b and c. The circuit breakers that tripped are shown in Figure 11, which is a view of the circuit breaker panels and the damaged wire harness in the background. There were 3 ac breakers and 5 dc breakers that tripped as a result of the impact. They were not reset and the test was ended so that the damaged harness could be more closely examined in the laboratory.

2. MIL-W-22759/34 Harness Tests

The next wire harness that was tested was the one made-up with MIL-W-22759/34 type wires and cables. As was previously described, it was constructed as nearly as possible to have the same number of wires and cables as used to make the MIL-W-81381/11 harnesses. The procedures for the bullet and fragment impact tests were conducted in the same manner as that previously described.

a) .30-Caliber bullet

The projectile hit the midline of the harness. At the point of impact shown in Figure 12 it can be observed that at least one wire was severed, but no carbon formation can be seen and no circuit breakers were tripped.

b) .30-Caliber fragment simulator

The same harness was then repositioned to place an undamaged section closer to the terminal strips into the target area for another impact test. This time the .30-caliber fragment simulator projectile was used. Upon impact, this projectile produced much greater damage to the wire harness and caused a bright arc and a short circuit which tripped one circuit breaker. The duration of the arc was about 0.1 second (three frames of videotape). Figure 13 shows this arc immediately following the impact. When reset, there was no arc and the breaker remained closed.

Figure 14 shows the harness with the damaged wires. Even though many of the wires in the harness were badly damaged by the impact there were no flames or ensuing fire to further damage the remaining wires.

CONCLUSIONS

As observed, and illustrated by the photos, arcing from the short circuits was just as intense for each type of wire. But, despite the presence of the same electrical energy the wires employing the aromatic polyimide insulation ignited and burned; whereas the wires employing the modified ethylene tetrafluoroethylene polymer did not burn.

From these experiments it is evident that it is the characteristics of the insulating materials on the wires tested that determined the reactions resulting from the initial short circuits produced when the wires were crossed by the shearing forces of the impacting projectiles.

It was observed that the aromatic polyimide forms a charry, carbonaceous residue when exposed to the heat of the arcs and flames. This char appeared to be electrically conductive so that as the flames propagated along the harnesses more short circuiting occurred, and the resulting arcs of the additional short circuits added more heat and combustion to the fire as it progressed from the zone of impact. Each short circuit tripped another circuit breaker, so that conceivably all power circuits in a harness could be lost from one impact.

The significant difference between the two materials compared in this experiment seems to be that the aromatic polyimide carbonizes when exposed to the intense heat of an electrical arc; whereas the modified ethylene tetrafluoroethylene polymer does not when exposed to the identical short duration arc of the impact.

Although the precise proximity of potentially shorting combinations of wires and cables was uncertain in the harnesses as constructed, the ballistic impacts produced a high probability of short circuiting. The significant fact is that in each instance where shorting occurred the harnesses made with aromatic polyimide insulation suffered additional damage from combustion of the insulation; whereas no subsequent fire ensued in harnesses made with the modified ethylene tetrafluoroethylene insulation.

Additional tests are desireable to document the frequency of shorting on impact which has now been demonstrated for the .17-caliber sphere, .30-caliber fragment simulator and .50-caliber ball projectiles. Refinements in experimental procedure which could add to the circumstance resulting from impact are:

a) Monitoring of the electrical phase at the instant of guillotining.

b) Measuring the energy of the electrical arcs.

c) Measuring the circuit breaker tripping times.

d) Simulation of the effects of electrical loads on $L\frac{di}{dt}$ and recovery voltage as affected by the voltage regulator.

e) Precision arrangement of the wires and cables in each harness in order to obtain more precise correspondence of mechanical damage to identical electrical circuits.

f) Orientation of the harnesses to maximize the flue effect on the burning wires.

g) Determining the minimum impact conditions which will consistently produce arcing in representative harnesses.

Nevertheless, since the present harnesses were constructed as being representative of F-14 wiring as specified by F-14 maintenance engineers and they were impacted with a variety of representative projectiles, the damage and the reactions to the damage are considered a valid combat vulnerability assessment of the wire insulations that were evaluated.

ACKNOWLEDGMENTS

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Table I. Descriptions of the Wire Harnesses

Wire Functions	Voltage	Number of Wires: Representative F-14 Harness	Specimen Harnesses 81381/11	Specimen Harnesses 22759/34
Power lines	115 V, 3-phase	10	12	12
Inter-control	28 V, dc	15	14	14
Signal wires				
unshielded	5 volts	20	19	20
shielded	5 volts	50	49	35
Cables	(grounded shields)	10	10	10
Ground leads	0	10	10	10

Table II Wires and Cables in Harness of Type MIL-W-81381/11

SINGLE WIRES

Circuit Beaker (amperes)	Voltage	Wire Size	Circuit Tracing ID Number
5	115 phase 1	24	ASN 92-81 A24
5	2	24	ASN 92-92 A24
3	3	24	ASN 92-83 A24
3	1	22	D414 B 22
3	2	22	ASN 92-126B 22
5	3	22	APX 832B 22
5	1	20	Q 305 B 20
5	2	20	Q 300 F 20
7.5	3	20	Q 324 J 20
3	1	16	AWG 9 116 A16
3	2	16	AWG 9 135 A16
3	3	16	AWG 116 A16
7 1/2	28 v	22	C993A22
7 1/2		22	D103A22
5		22	AWG9-281G22
7 1/2		20	Q 303 C 20
7 1/2		20	Q 324 M 20
7 1/2		20	Q 302 B 20
7 1/2		20	AWG 9-192 C 20
7 1/2		20	GC875MR1-245H92607
5		20	not legible
5		16	ARC 159-231J 16
7 1/2		16	AWG 9 99A16
7 1/2		16	AWG 9 1214A16
5		16	AWG 9 1213A16
7 1/2		16	AWG 9 1885 16

	No. of wires	Size
floating:	5	26
	4	22
	10	24
grounded:	6	22
	3	24
	1	26

CABLES

ID NO.	#Wires	Size
GC875MR8-26SH 05973	8	26
GC875MR8-26SH 05973	8	26
GC875MR3-20S 05973	3	20
----------	6	26
----------	8	26
----------	5	26
GC875MR3-20S 05973	3	20
----------	2	20
----------	2	20
----------	2	20

Table III

WIRES AND CABLES IN HARNESS OF
TYPE MIL-W-22759/34
SINGLE WIRES

Circuit Breaker (amperes)	Voltage	Wire Size	Wire ID Number
5	115 Phase 1	20	M 22759/34-20 06090
5	2	20	"
3	3	20	"
3	1	20	"
3	2	20	"
5	3	20	"
5	1	20	"
5	2	20	"
7.5	3	20	"
3	1	14	M 22759/34-16 06090
3	2	14	"
3	3	14	"
7 1/2	28	22	M22759/34-22 06090
7 1/2		22	"
5		22	"
7 1/2		20	M22759/34-20 06090
7 1/2		20	"
7 1/2		20	"
7 1/2		20	"
5		20	M22759/34-20 06090
5		16	M22759/34-16 06090
7 1/2		16	"
7 1/2		16	"
5		16	"
7 1/2		16	"

	No. of Wires	Size
floating	20	26
grounded	10	26

CABLES

ID	#Wires	Size
M27500-20 SB 2T23 06090	2	20
"	2	20
"	2	20
"	2	20
"	2	20
M 27500-16 SB 3T23 06090	3	16
"	3	16
"	3	16
"	3	16
"	3	16

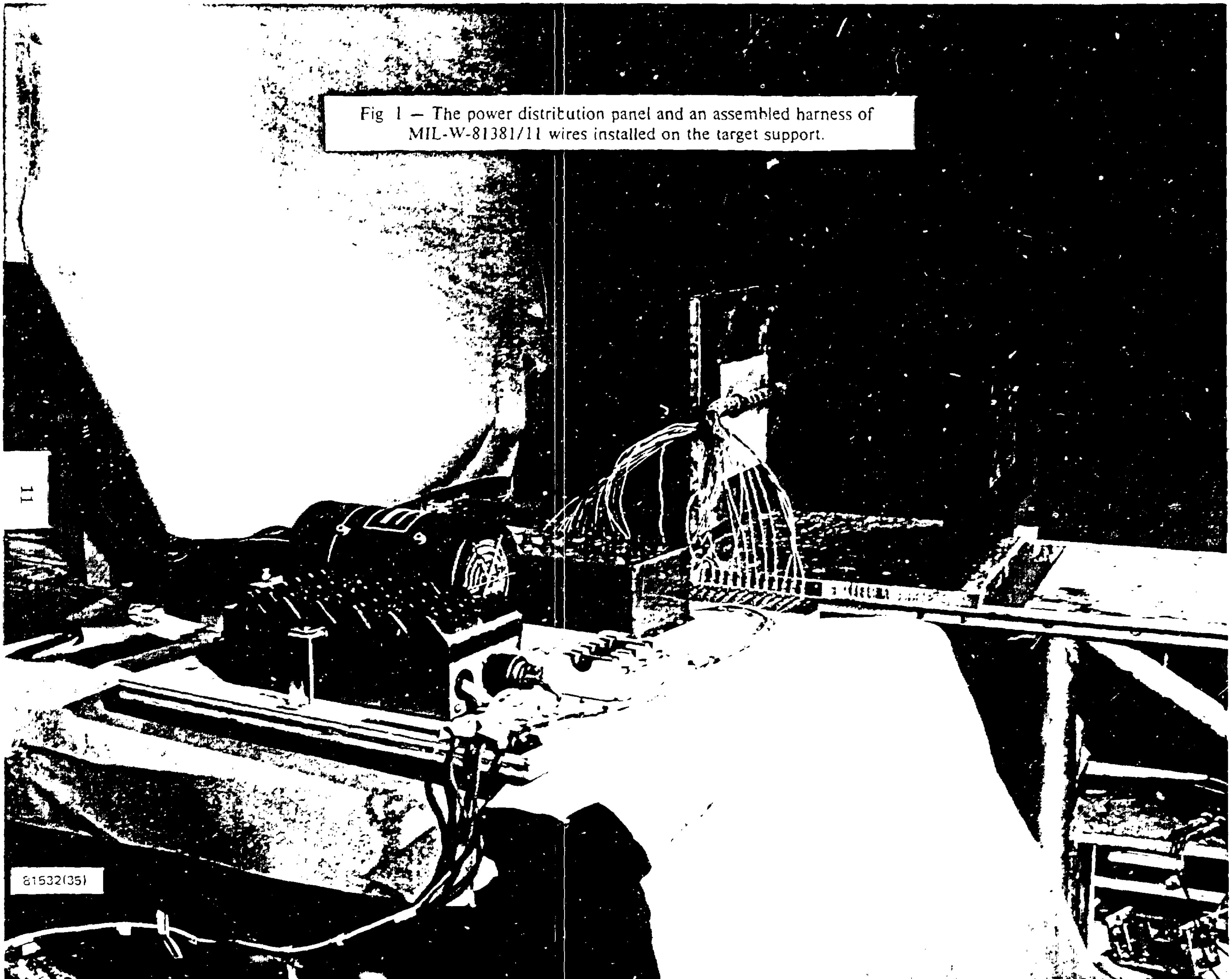

Fig 1 — The power distribution panel and an assembled harness of MIL-W-81381/11 wires installed on the target support.

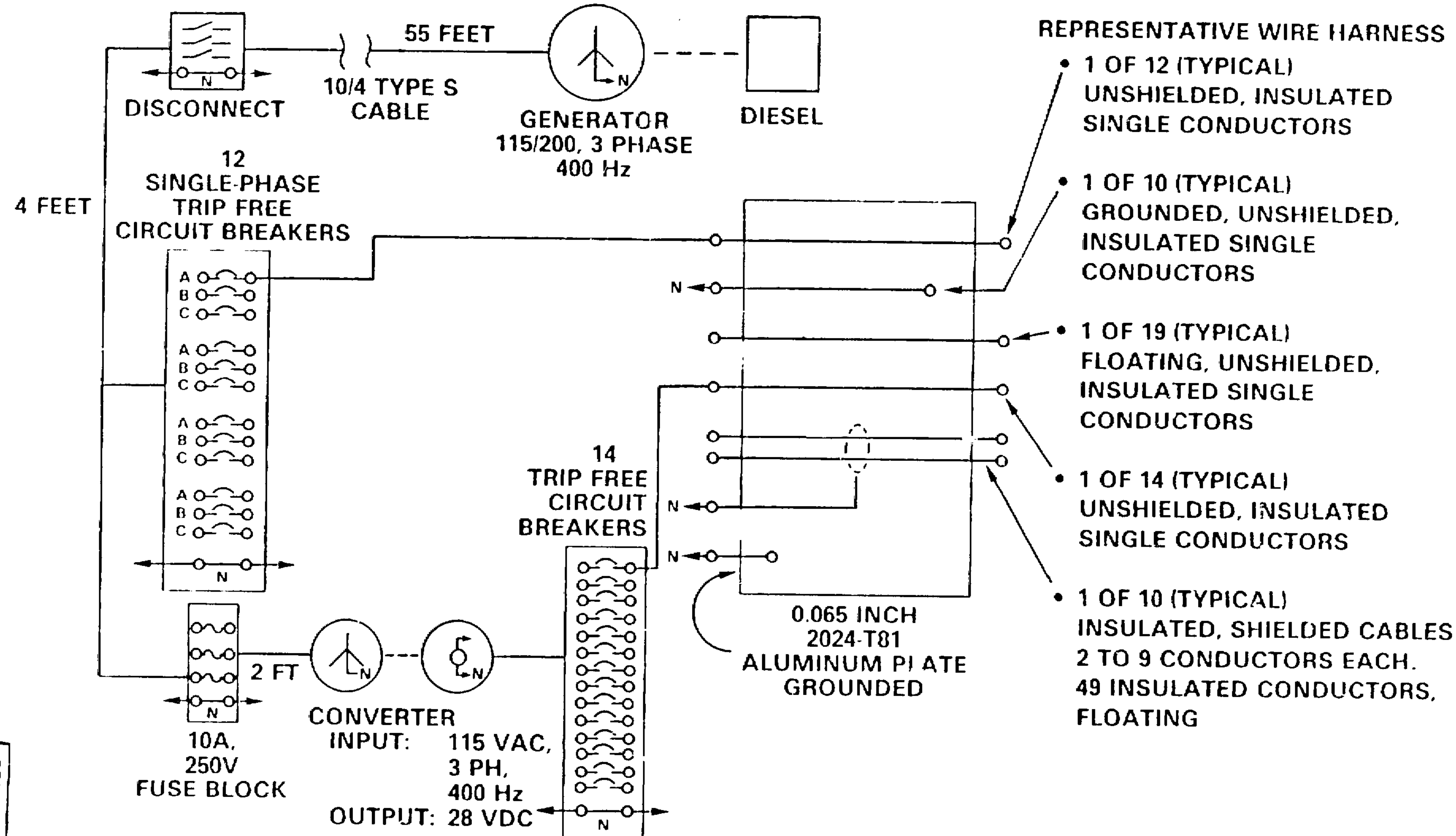

Fig. 2 — Schematic of the electrical system.

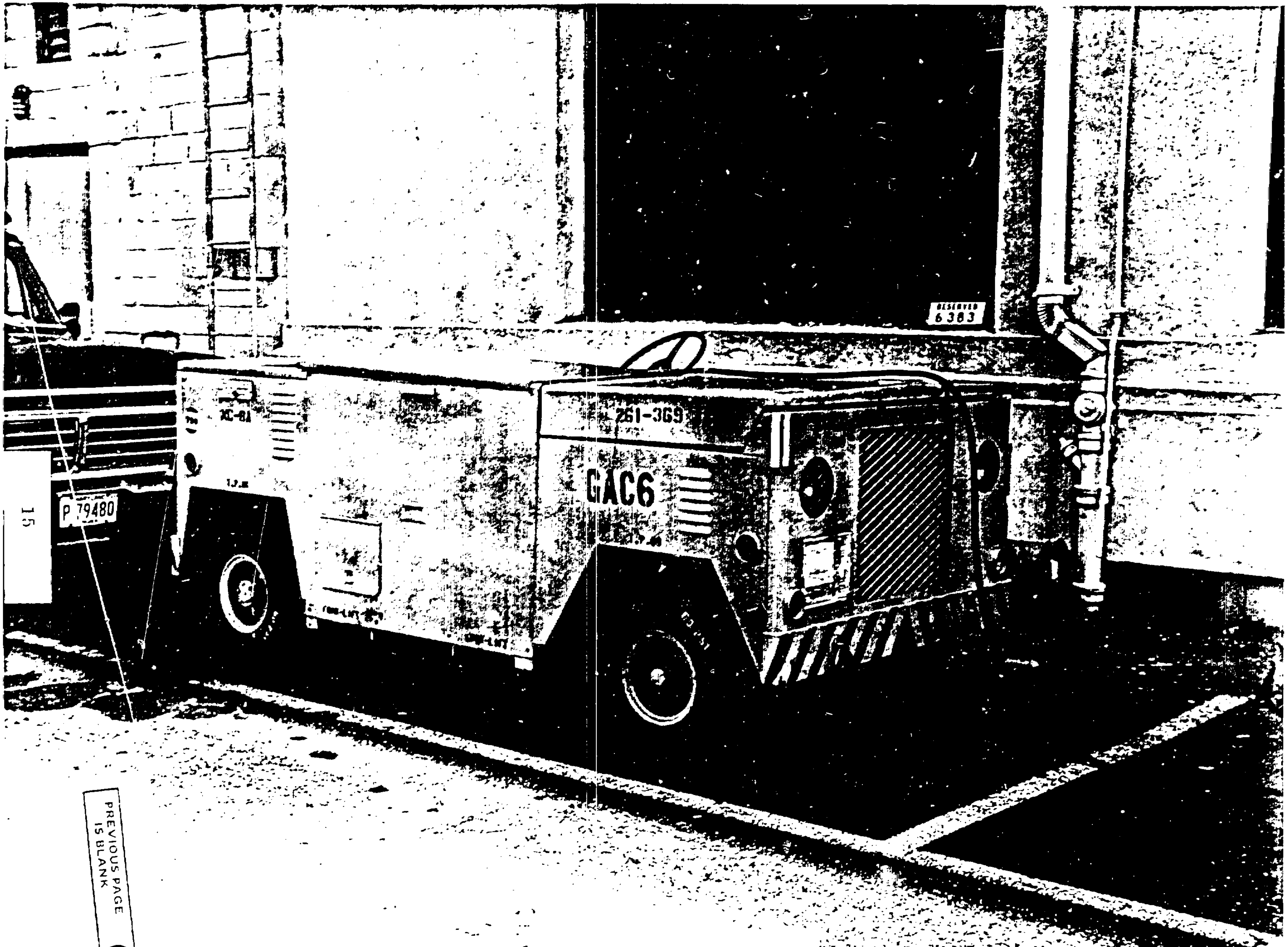

Fig. 3 — The NC-8A Mobile Electric Power Plant used to provide the power to the wire harnesses

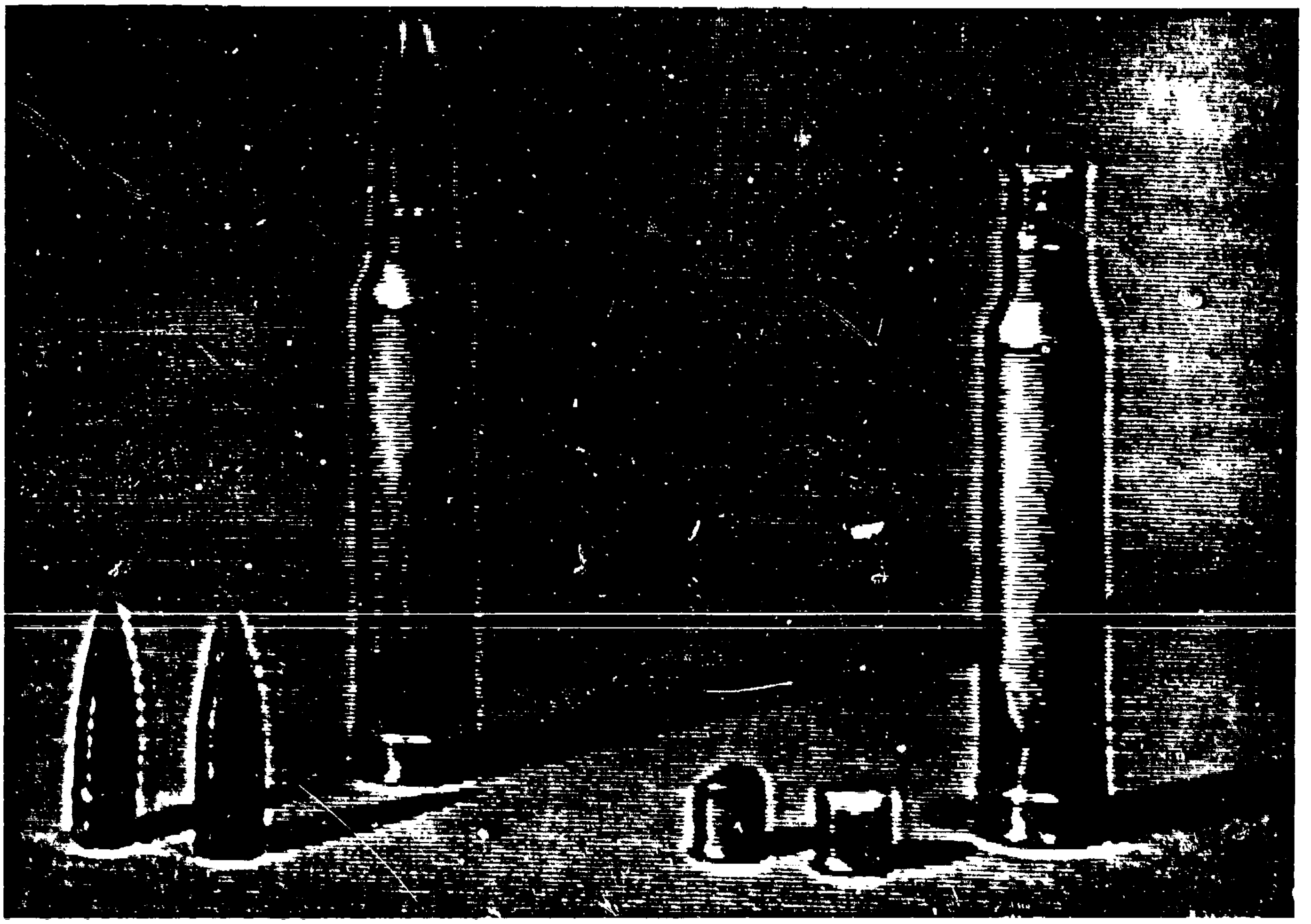

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Fig. 4 — The projectiles used in the impact experiments:
left—bullets, right—fragment simulators.

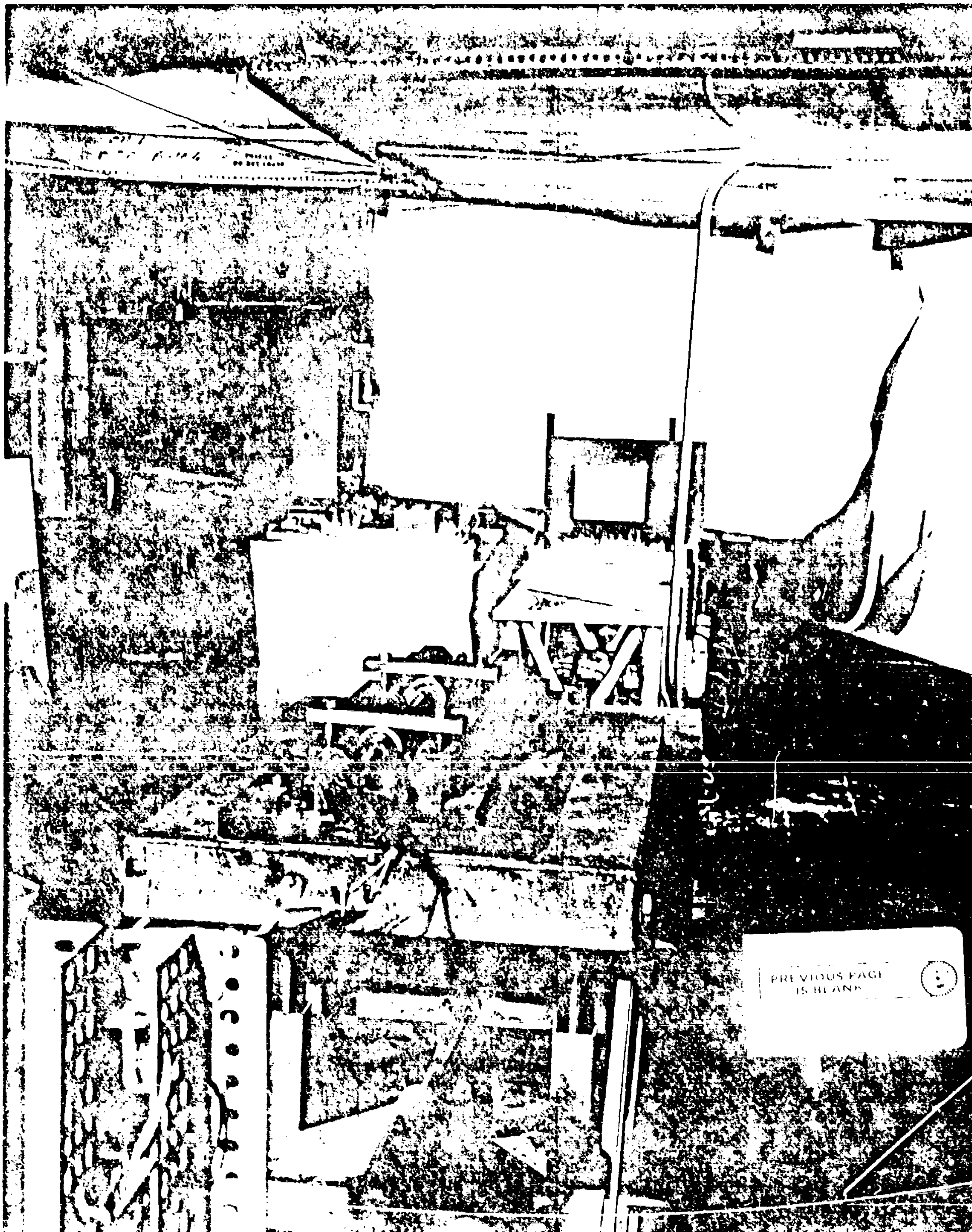


Fig. [illegible] — An overview of the [illegible]

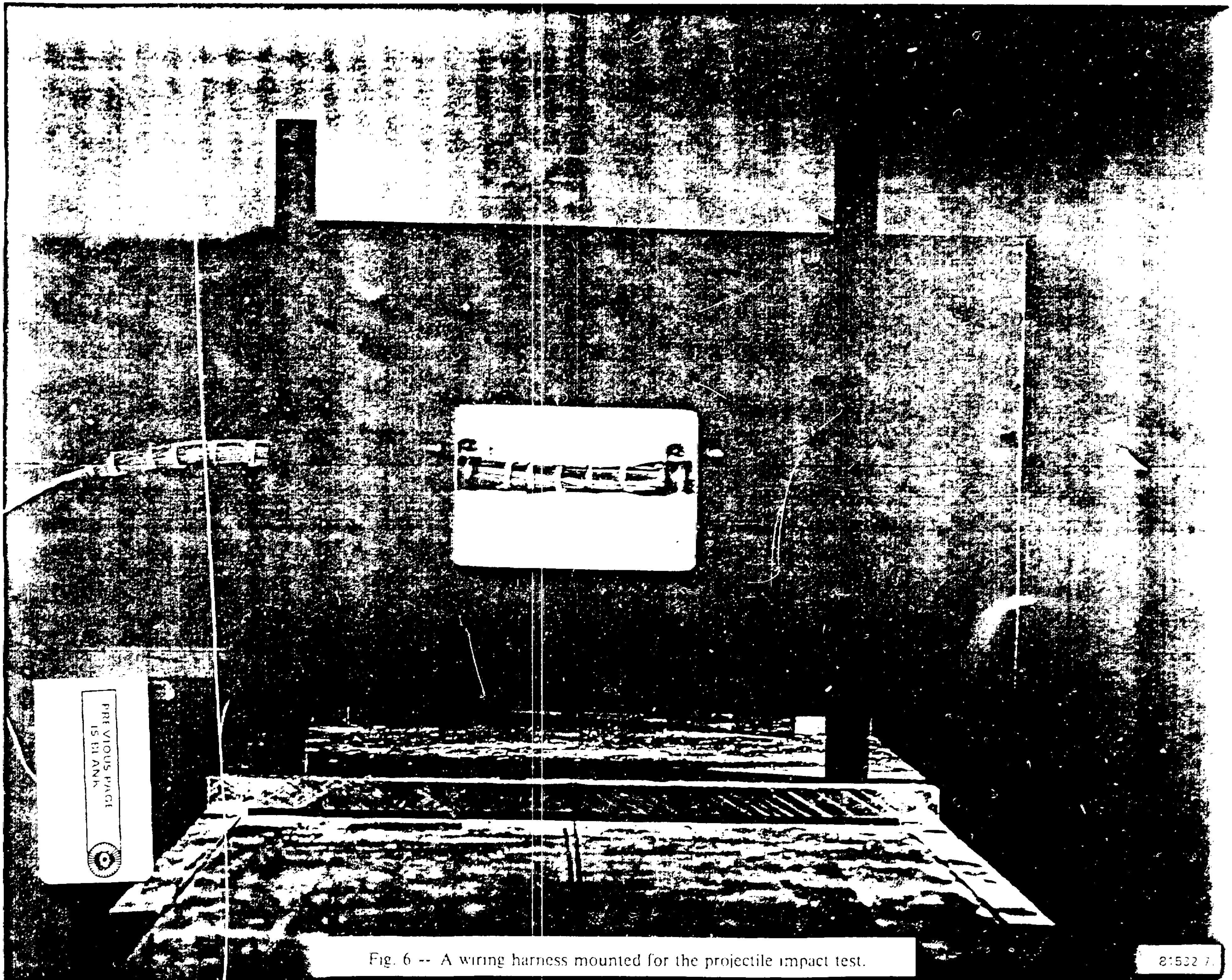


Fig. 6 -- A wiring harness mounted for the projectile impact test.

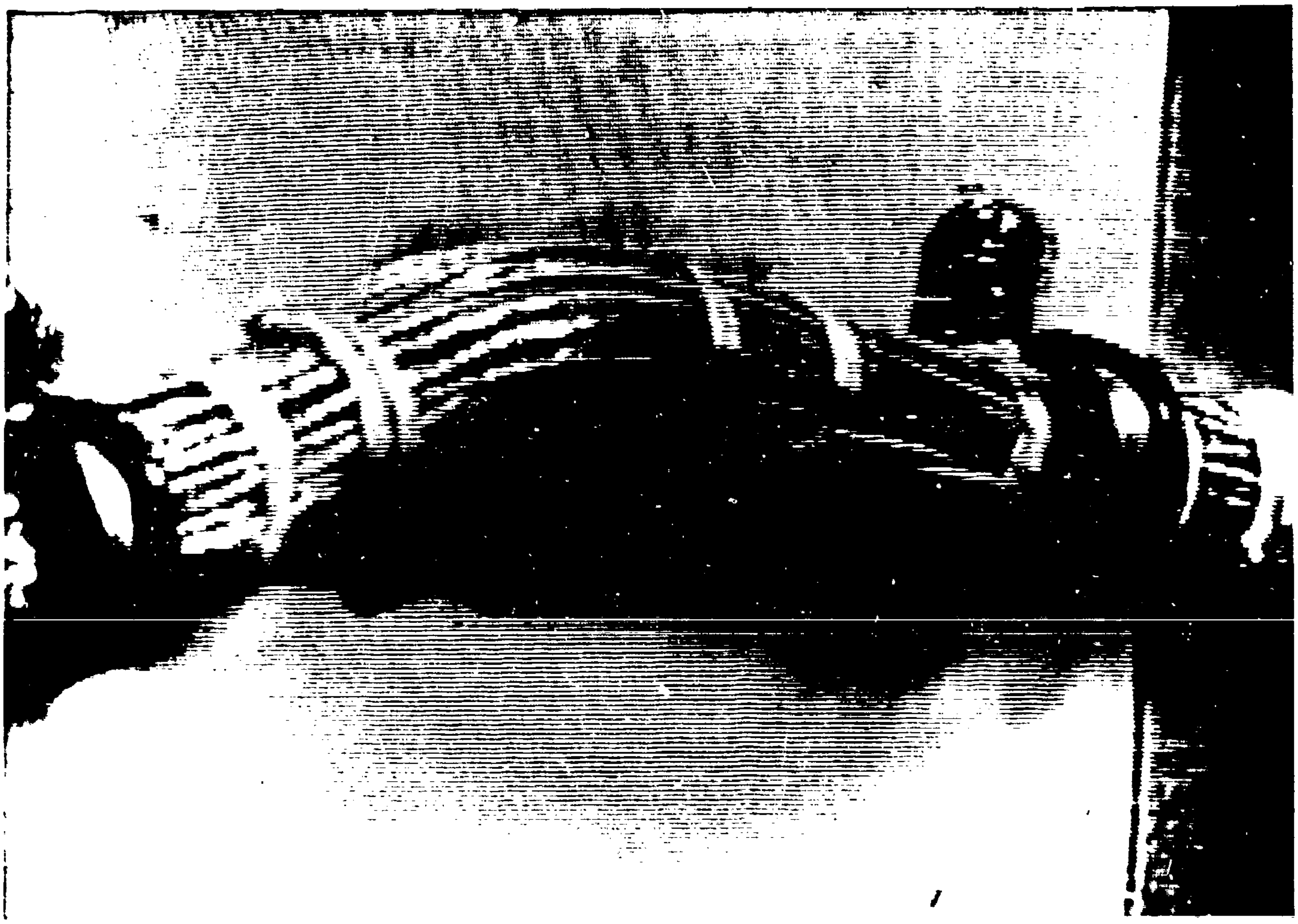


Fig. 7 — The initial damage to the MIL-W-81381/11 harness from the impact of a .30-caliber bullet.

81612-3

81602-14

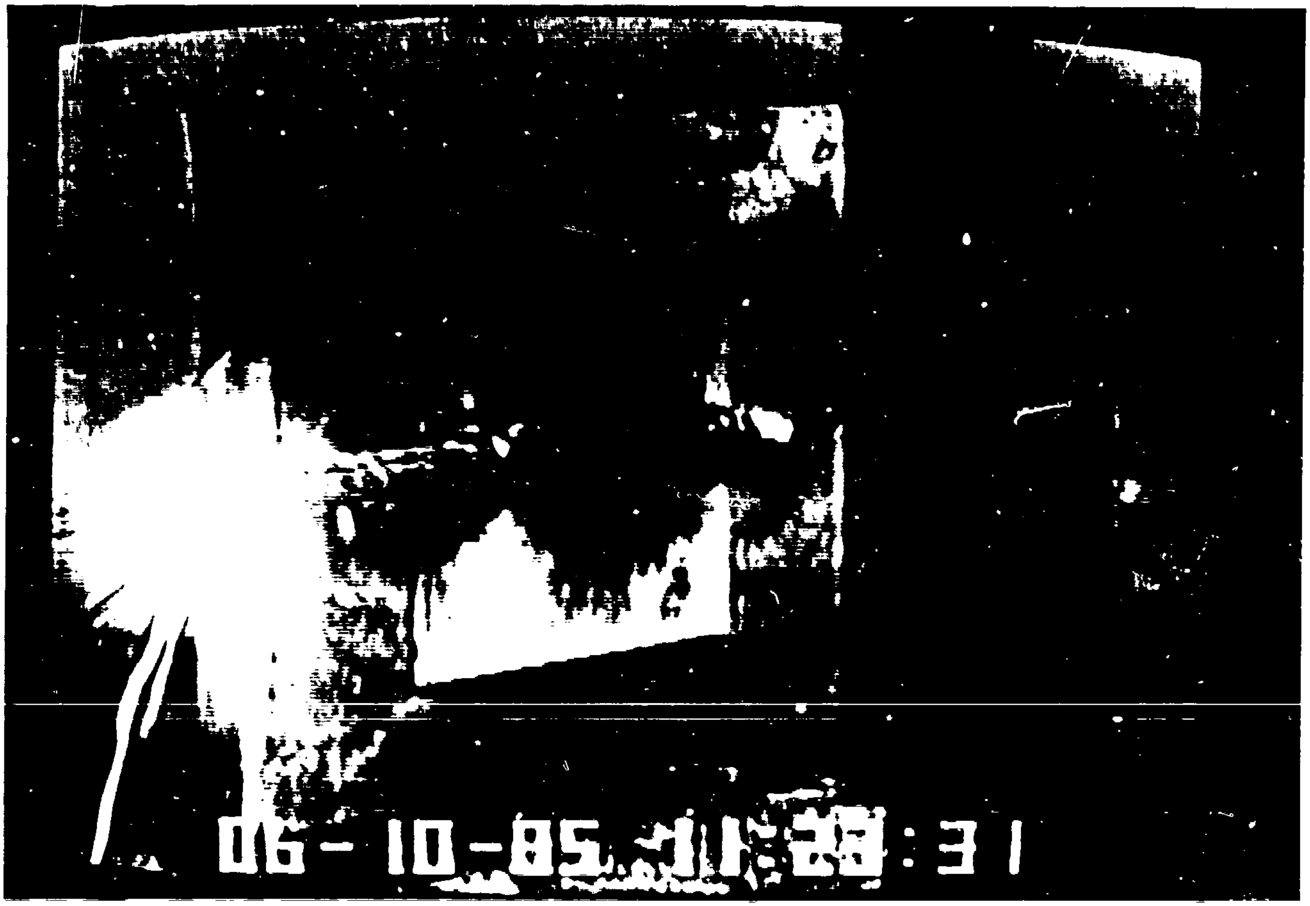
a. fire near the initial damage

Fig. 8 — The burning harness of MIL-W-81381/11 wires which ignited when circuit breakers were reset after it was initially damaged by the impact of a .30-caliber bullet.

81E02-11

b. two seconds later, flames and arcing are spreading

Fig. 8 (Cont'd) — The burning harness of MIL-W-81381/11 wire which ignited when circuit breakers were reset after it was initially damaged by the impact of a .30-caliber bullet



81602-9

c. seventeen seconds later, flames and arcing are propagating along the harness.

Fig. 8 (Cont'd) — The burning harness of MIL-W-81381/11 wires which ignited when circuit breakers were reset after it was initially damaged by the impact of a .30-caliber bullet

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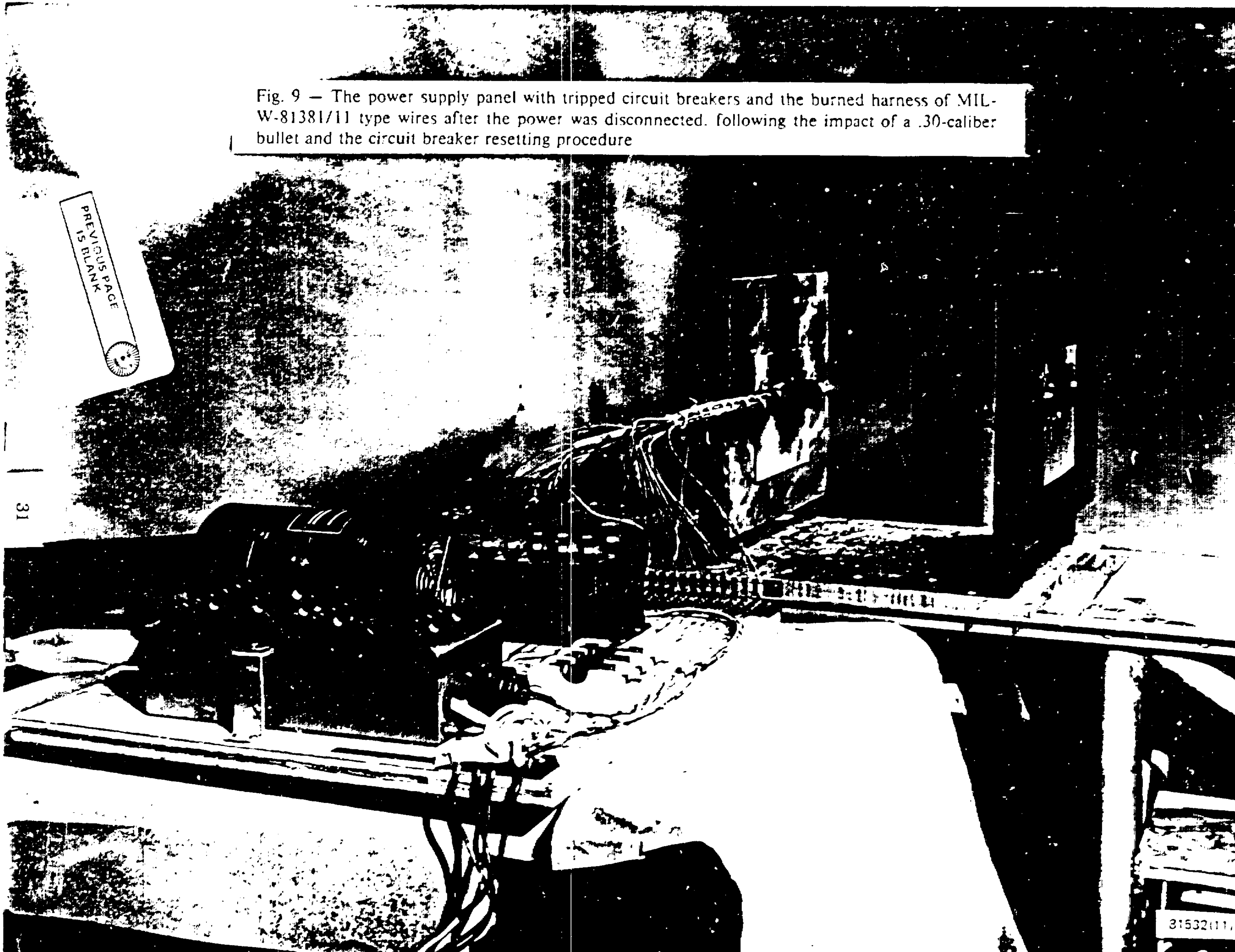
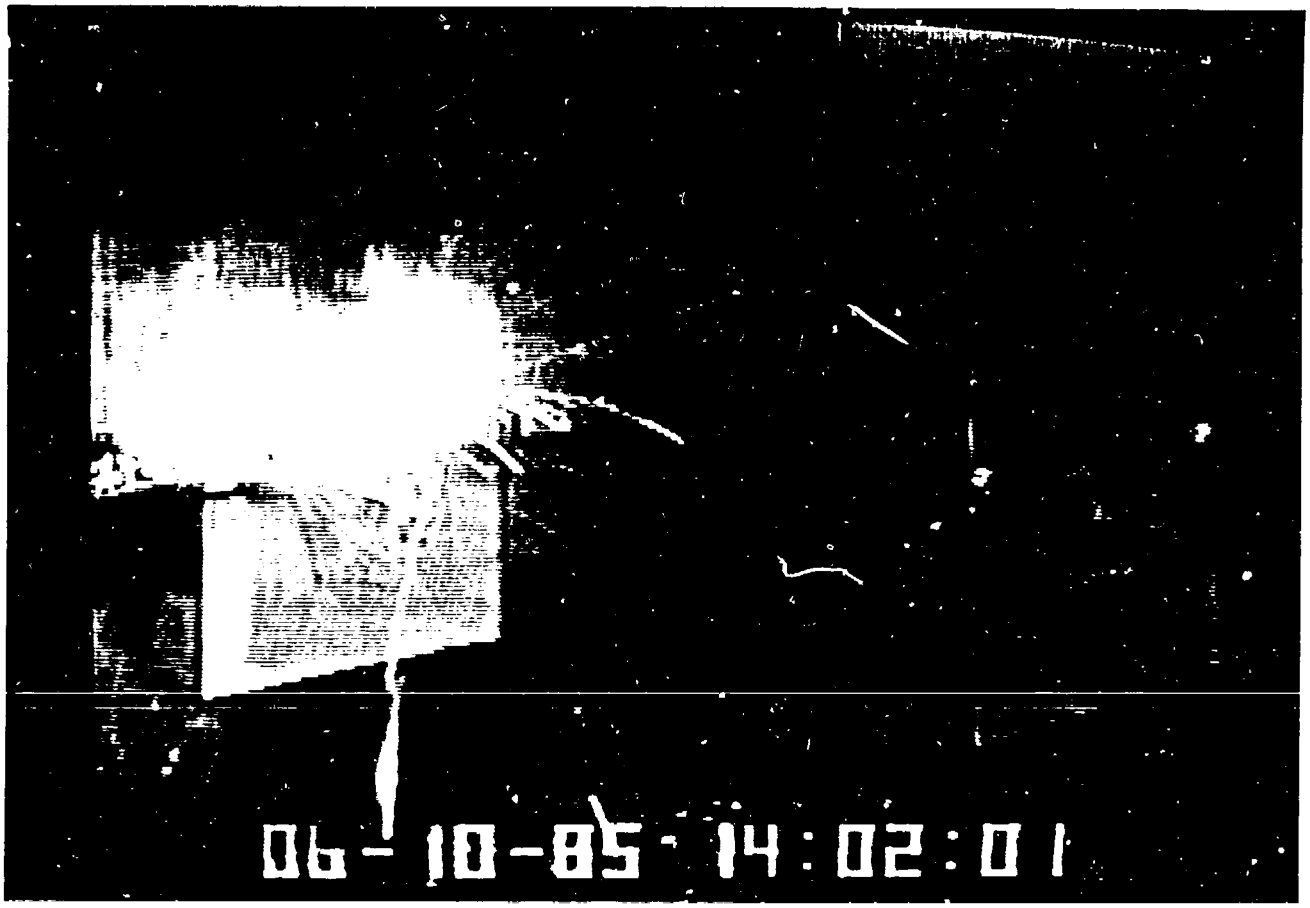


Fig. 9 — The power supply panel with tripped circuit breakers and the burned harness of MIL-W-81381/11 type wires after the power was disconnected, following the impact of a .30-caliber bullet and the circuit breaker resetting procedure

a. initial arcing

81602-3

Fig. 10 — Arcs and flames initiated by the impact of the fragment simulator on the harness of MIL-W-81381/11 type wire.



81602-20

b. one second later

Fig. 10 (Cont'd) — Arcs and flames initiated by the impact of the fragment simulator on the harness of MIL-W-81381/11 type wire.

81602-23

c. three seconds later

Fig. 10 (Cont'd) — Arcs and flames initiated by the impact of the fragment simulator on the harness of MIL-W-81381/11 type wire

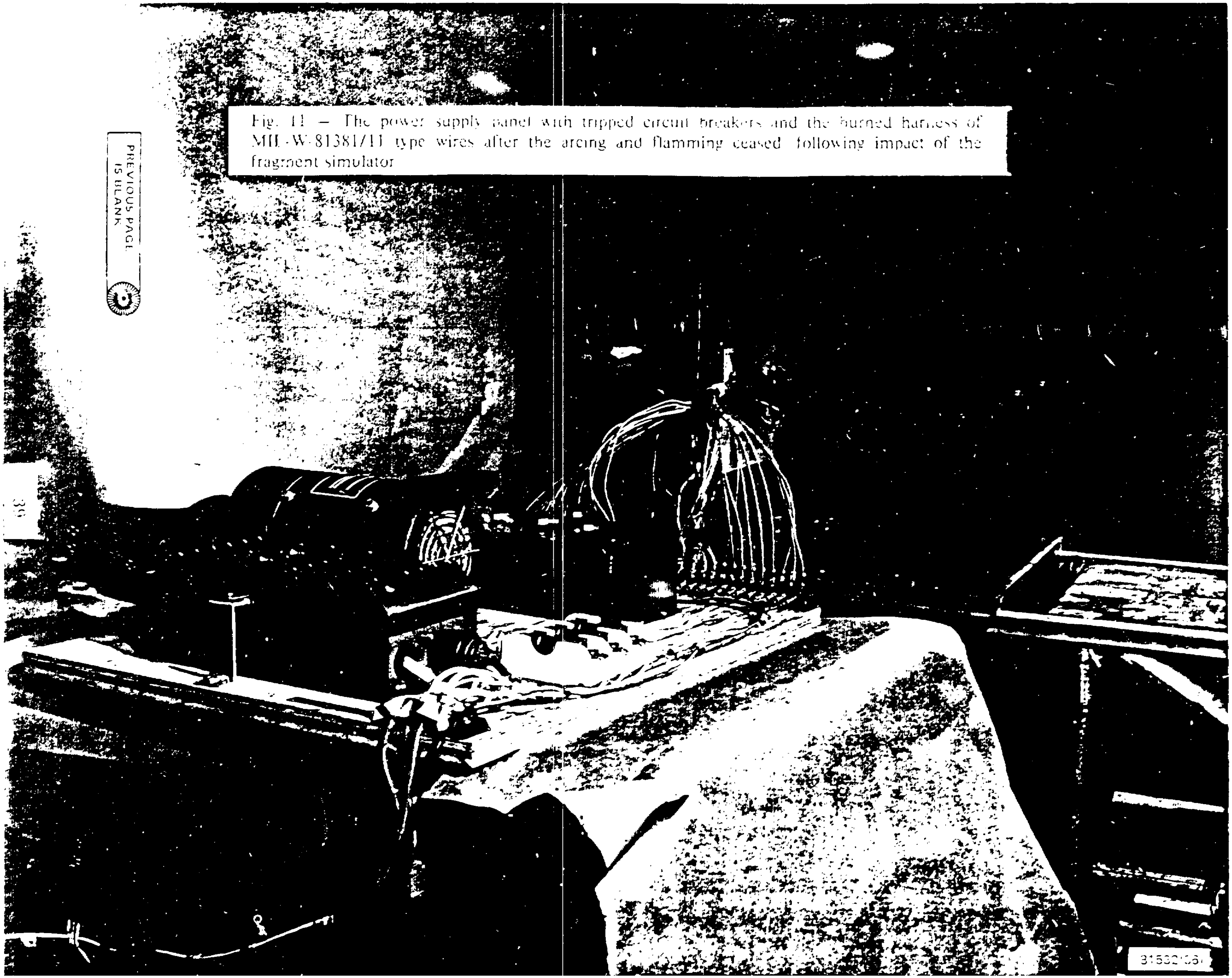


Fig. 11 — The power supply panel with tripped circuit breakers and the burned harness of MIL-W-81381/11 type wires after the arcing and flamming ceased following impact of the fragment simulator

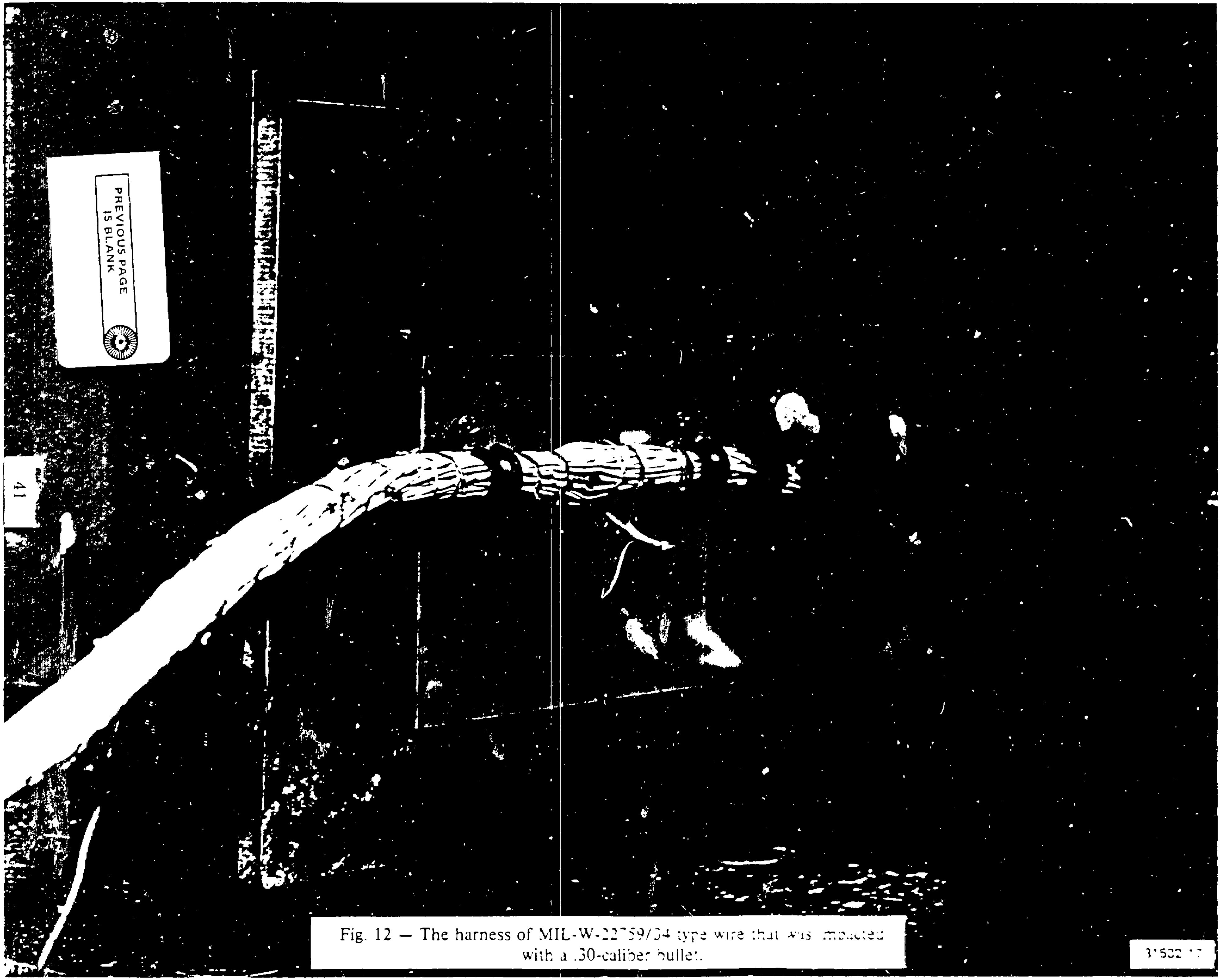
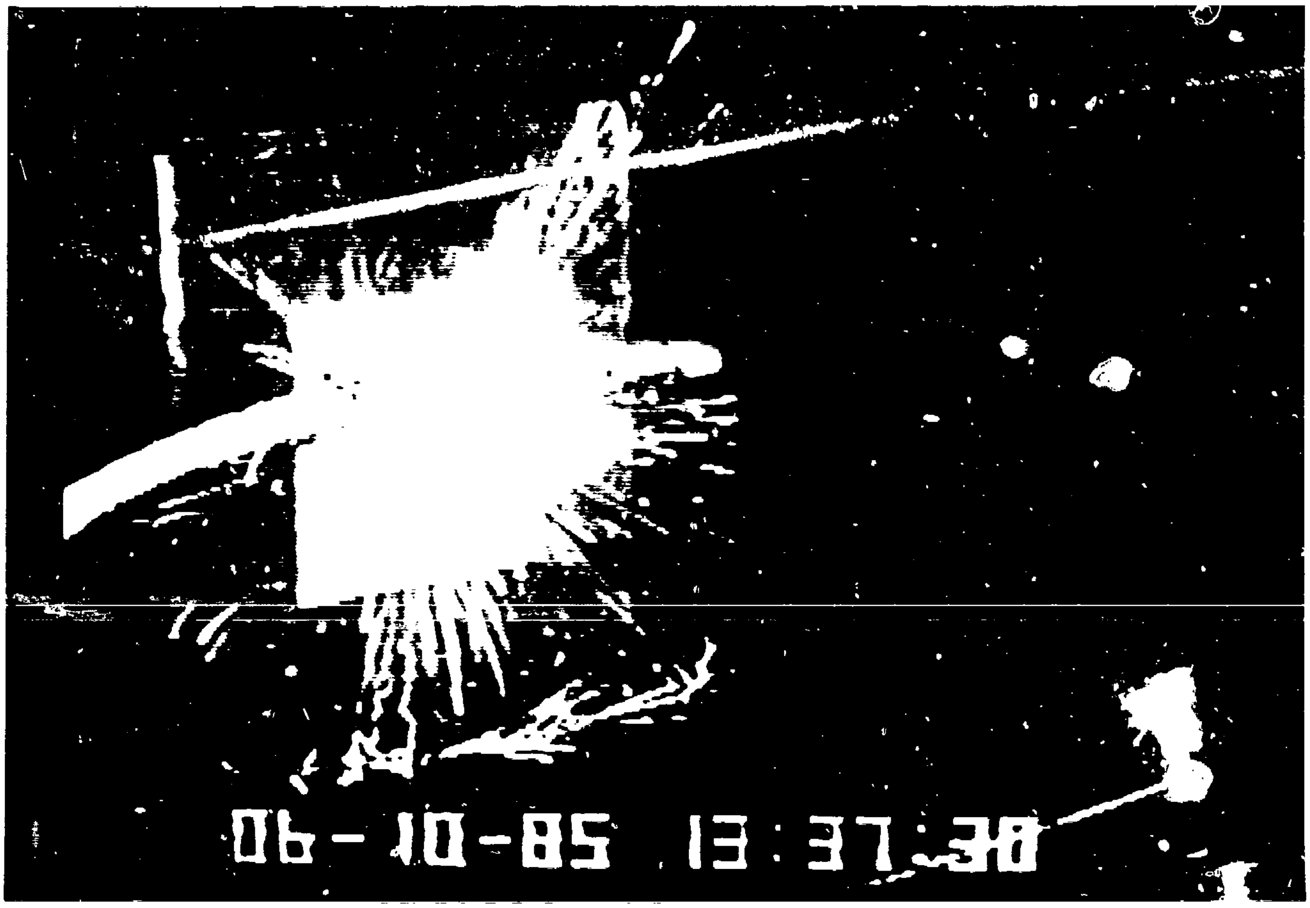


Fig. 12 — The harness of MIL-W-22759/34 type wire that was impacted with a .30-caliber bullet.



R1602-6

Fig. 13 — The arc produced by the impact of a .30-caliber fragment simulator on a harness of MIL-W-22759/34 type wire.

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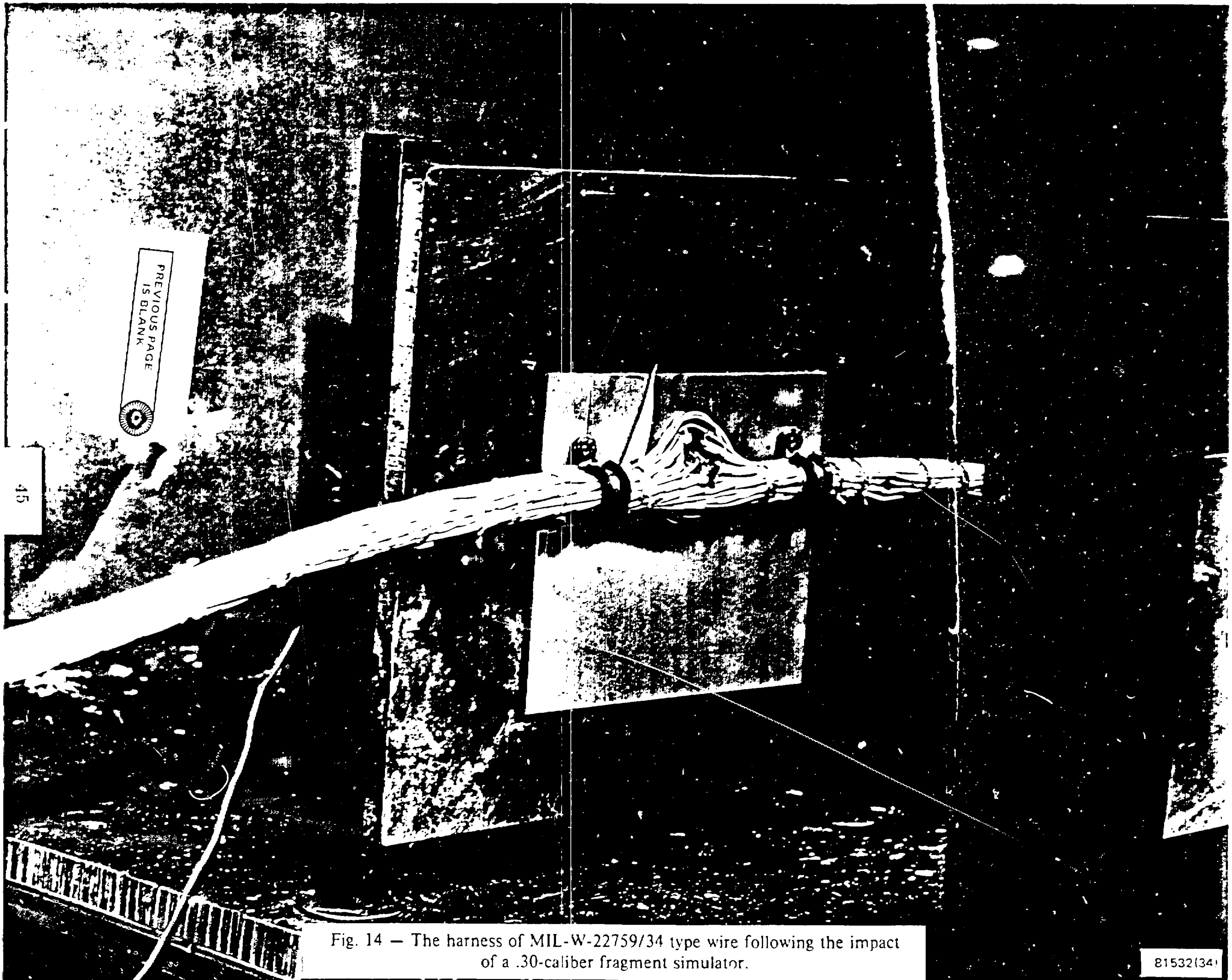

Fig. 14 — The harness of MIL-W-22759/34 type wire following the impact of a .30-caliber fragment simulator.

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